**HOW SHOULD PLANETARY MAP UNITS BE DEFINED?**

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**Introduction:** Planetary geologic maps are inherently different from typical terrestrial geologic maps in the character of "geologic units" as well as in the hypothetical nature of most unit contact relationships. Geologic units separated by various contacts are meant to distinguish materials of distinctive lithology and/or formation age. In practice, map units are characterized by what are interpreted to be primary morphologies, textures, or other attributes, by ages relative to adjacent units, and/or by cross-cutting or buried structures or landforms. However, there are several problems that have afflicted planetary geologic maps including (1) definitions of map units based on *secondary* morphologic features, which yield little or no information as to the genesis of the original surface, and (2) subdivision of sequences of a similar "lithology" without strong evidence for intervening hiatuses. Such misrepresentation of planetary geologic units often resulted in unorganized unit divisions within a weak stratigraphic framework, which only complicates and, perhaps, biases the geologic story.

Based in part on recent mapping efforts in the martian northern plains and surrounding areas [1], we propose a revision in mapping approach that includes the separation of material units into two distinctive types based on certain criteria. These revisions should facilitate more meaningful stratigraphic divisions and improve objectivity of geologic maps. Furthermore, our approach will maintain the flexibility necessary for the incorporation of future datasets. Though our revisions are based on material relationships observed in the martian northern plains, they are equally applicable to other planetary surfaces.

The delineation of appropriate planetary map units and documentation of their relationships with adjacent materials involve a multitude of interesting challenges, many of which arise from an inability to verify a unit's character in the field. Further challenges arise through the use of multiple dataset types and scales. Map unit revisions are unavoidable due to increases and improvements in surface data quality, variety, and resolution, as is currently the case for Mars geologic mapping. Many geologic maps have relied upon surface structures to define the boundaries of geologic units, a method of morphologic mapping. There has been little effort to differentiate primary and secondary surface features in the characterization of map units, adding unnecessary ambiguity to unit definition and interpretation. Secondary morphologies and structures should be represented independently from unit classification.

Because of these issues, we feel that it is time to reassess the philosophy of mapping planetary surfaces. Most geologic maps attempt to define planetary geologic units as rock-stratigraphic units based on lithology and/or age [1-4, 7]. However, in practice, we map units such as highland rocks that include a variety of uncertain lithologies. At best, we are mapping a resolvable "packages" of lithologically diverse materials that formed during a given period in a particular geologic setting. Terrestrial stratigraphic guidelines permit accommodation of such units as allostratigraphic units, defined as sequences of discontinuity bound materials [5-6]. We propose that if a certain set of criteria cannot be fulfilled to define units as either rock-stratigraphic or allostratigraphic unit types, then alternative means of mapping the geologic features exclusive of using map units should be assessed. The potential methods of implementing these mapping revisions as well as their strengths are discussed below.

**Surface Classification:** Past literature dealing with the division and classification of surface units on Mars have concentrated on defining lithostratigraphic units [2-3], commonly a misnomer based on our inability to confidently differentiate lithologic variation at map scale. Rock "types", however, can be inferred through morphologies interpreted to have formed from emplacement processes and, to a lesser degree, weathering and erosion. These types of materials form *rock-stratigraphic units*. Examples of rock-stratigraphic units can include lava flows (based on lobate flow margins), sedimentary materials (based on strata), ergs (based on laterally expansive dunes), and impact breccias (based on variously degraded crater morphologies). Rock-stratigraphic units are defined based on the lateral extent of characterizing primary surface features, the edge of which may be variably expressed by embayment, burial, and truncation relations [2-3]. These units are primarily classified based on their inferred rock type and have little inherent connotation to event or episode. For example, a group of lobate flow materials surrounding a low shield could effectively be mapped as a single rock-stratigraphic unit, regardless of whether the more distal flows are interpreted to be older than the proximal flows.

The second unit type useful for planetary mapping is the *allostratigraphic unit*, which may be composed of multiple lithologies interpreted to have formed during a single continuous (or relatively continuous) event or episode [2-3]. The strength of delineating allostratigraphic units over lithostratigraphic units is that allostratigraphy encourages the recognition and correlation of genetic packages of materials rather than lithologically similar material units [4]. Allostratigraphic units are defined by upper and lower discontinuities, each of which represents a hiatus in emplacement. Discontinuities can be identified in remotely sensed datasets by cross-cutting relationships with bounding structures. Examples of potential allostratigraphic units include highland and lowland mixtures of impact breccias, volcanic rocks, and sedimentary deposits as well as volcanic episodes relating to discrete eruptive episodes.

**Implementation:** Perhaps the most notable result of integrating these new mapping terminologies and unit classifications will be to reduce the overall number of map units. However, the separation of surface structures and morphologies does not remove the need to represent these features. On the contrary, the location and distribution of surface features are integral to interpreting the geologic history of a planetary surface. We encourage the use of diverse and well-defined geologic symbols or patterns to most appropriately define the relationships of material units and secondary morphologies and structures.

The U.S Geological Survey provides a diverse set of approved geologic map symbols that can be used to represent material characteristics [8]. Contact relationships we have found to best represent material relationships include certain (solid), inferred (long dashes), approximate (short dashes), buried (dotted) and gradational (hachured), though the use of these are subject to interpretation (see also [9]). The careful identification of types of geologic unit contacts using remotely-sensed datasets forces the mapper and the map user to look at the contacts as "hypothetical", that is, that all boundary locations and types represent inferences based on certain aspects of available data. Secondary features such as tectonic and erosional structures, landforms, and textures are most appropriately represented by distinct symbols or stipple patterns and should not be used as map unit identifiers.

The representation of map units in a stratigraphic column or correlation chart is necessary for an understanding of map unit age relationships. In addition, the identification of secondary surface morphologies that occur relative to certain map units provides an accurate, unbiased representation of their development. As such, the use of "geologic event column" has been used in a variety of geologic maps (notably Venus), and provides an indispensable means of documenting all major geologic activities on a correlation chart without unduly having to divide out additional map units.

**Method Benefits:** The foremost benefit of dividing surface units into either rock-stratigraphic or allostratigraphic units using established mapping criteria derived from the terrestrial mapping community is robust objectivity and unambiguous clarity. Such an approach should ease interpretive revisions using future datasets. Another notable benefit is that mapping units objectively by following established geologic criteria, nomenclature, and stratigraphic code to the highest level possible aids in the review process of geologic maps. Furthermore, should terrestrial geologists be requested to review planetary maps (a prudent idea raised at the most recent planetary mappers' meeting), maps that conform to nomenclature and code would help facilitate this process.

**Summary:** Approaches to mapping and understanding planetary surfaces and stratigraphy continue to evolve. However, the objective delineation of material units based on primary features and within established codes is fundamental to the proper planetary geologic mapping. The use of criteria to divide units into distinctive rock types (rock-stratigraphic or allostratigraphic) will aid in avoiding loose and uncontrolled mapping of planetary surfaces that may improperly bias or alter interpretation of a planet's geologic history. Though contact relationships and unit characteristics may change based on results from future missions, geologic maps can remain useful tools if their map units and stratigraphic relationships are delineated objectively and with interpretive flexibility.

**References:** [1] Tanaka K. L. et al. (2003) *JGR, 2002je001908*, in press. [2] Wilhelms D. E. (1987) in *Planetary Mapping*, R. Greeley and R. M. Baston (eds.). [3] Tanaka, K. L. et al. (1992) in *Mars*, pp. 345-382. [4] Oviatt, C. G. et al. (1994) *GSA Bull*, 106, 133-144. [5] *International Stratigraphic Guide* (1994) Salvador A., ed. [6] North American Stratigraphic Code (1983) *AAPG Bull*, 67, pp. 841-875. [7] Scott, D. H. et al. (1986-1987) *USGS Maps I-1802A,B,C*. [8] USGS Open File Report 99-430. [9] Hansen V. L. (2000) *EPSL*, 176, 527-542.